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Ruan

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(54) **PER WEDGE PREHEAT DFH TO IMPROVE DATA STORAGE DEVICE PERFORMANCE**

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CPC **G11B 5/607** (2013.01); **G11B 5/6011** (2013.01); **G11B 5/5521** (2013.01); **G11B 5/596** (2013.01); **G11B 5/6029** (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

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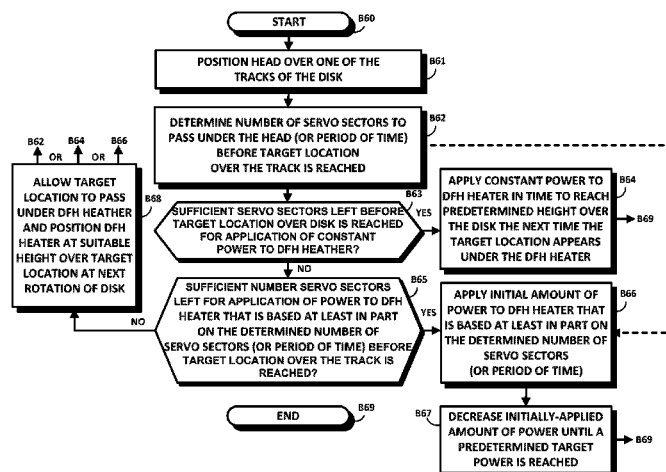
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ABSTRACT

A disk drive is disclosed including a disk having a plurality of tracks, wherein each track comprises a plurality of data sectors and a plurality of servo sectors. The disk drive further comprises a spindle motor for rotating the disk, and a head actuated radially over the disk, wherein the head comprises a dynamic fly height (DFH) heater. Control circuitry within the disk drive is operable to position the head over one of the tracks; determine a number of servo sectors to pass under the head before a target location over the track is reached, apply an initial amount of power to the DFH heater that is dependent at least in part on the determined number of servo sectors, and decrease the initially-applied amount of power applied to the DFH heater until a predetermined target power is reached.

16 Claims, 3 Drawing Sheets



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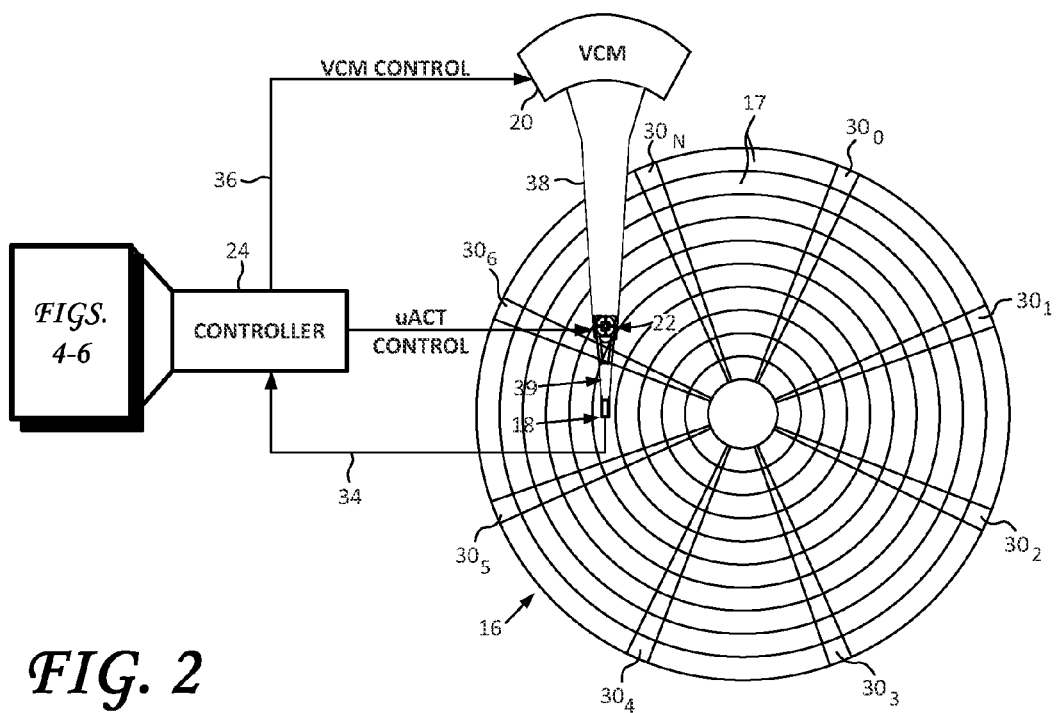
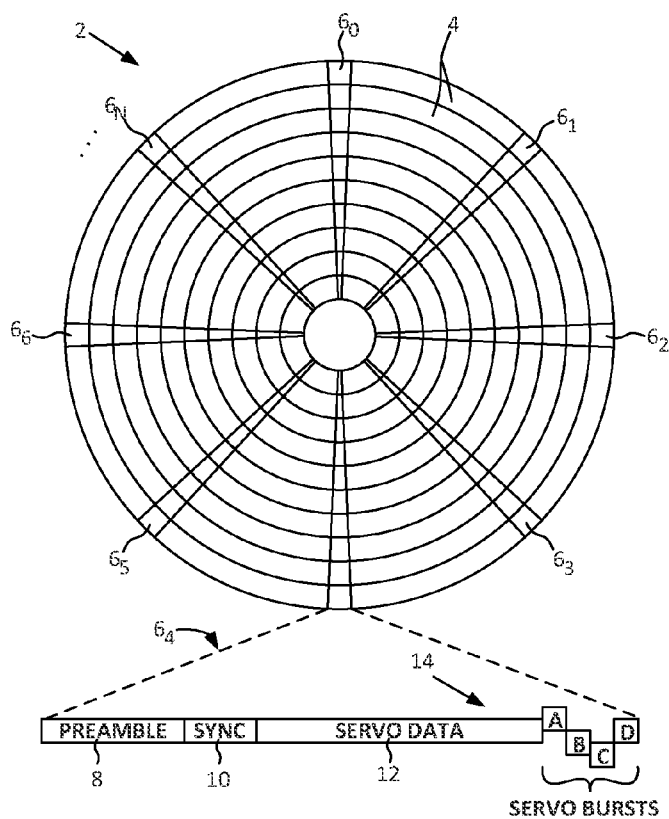
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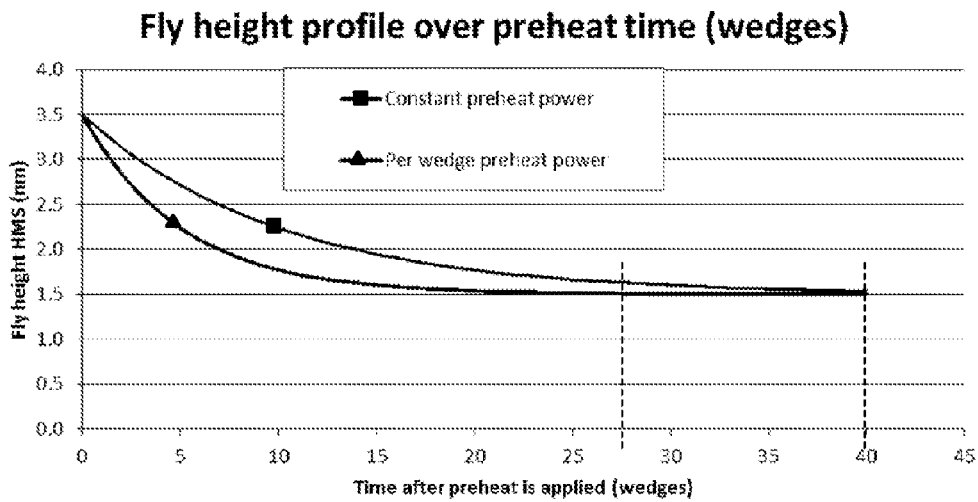
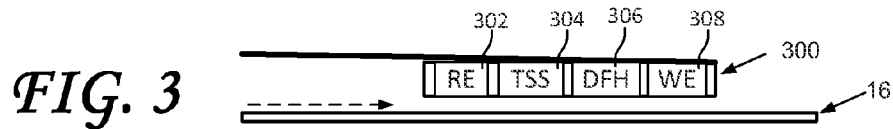
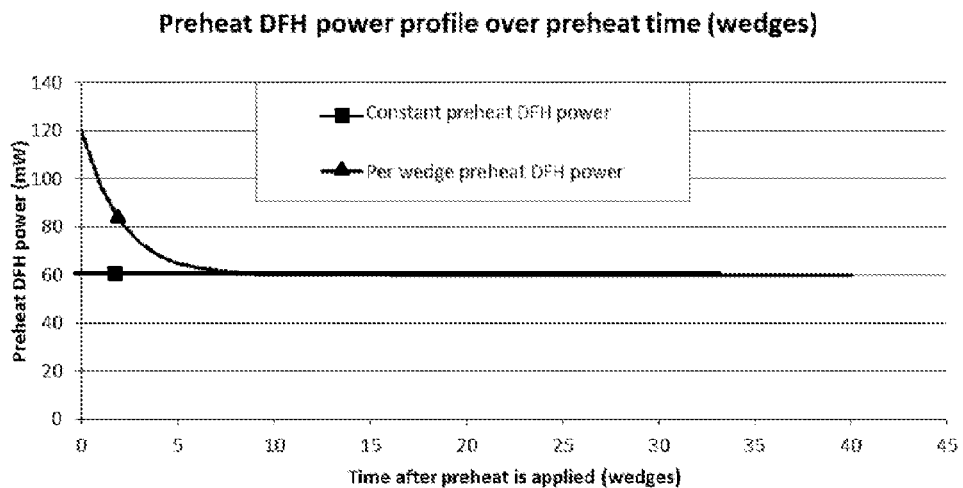
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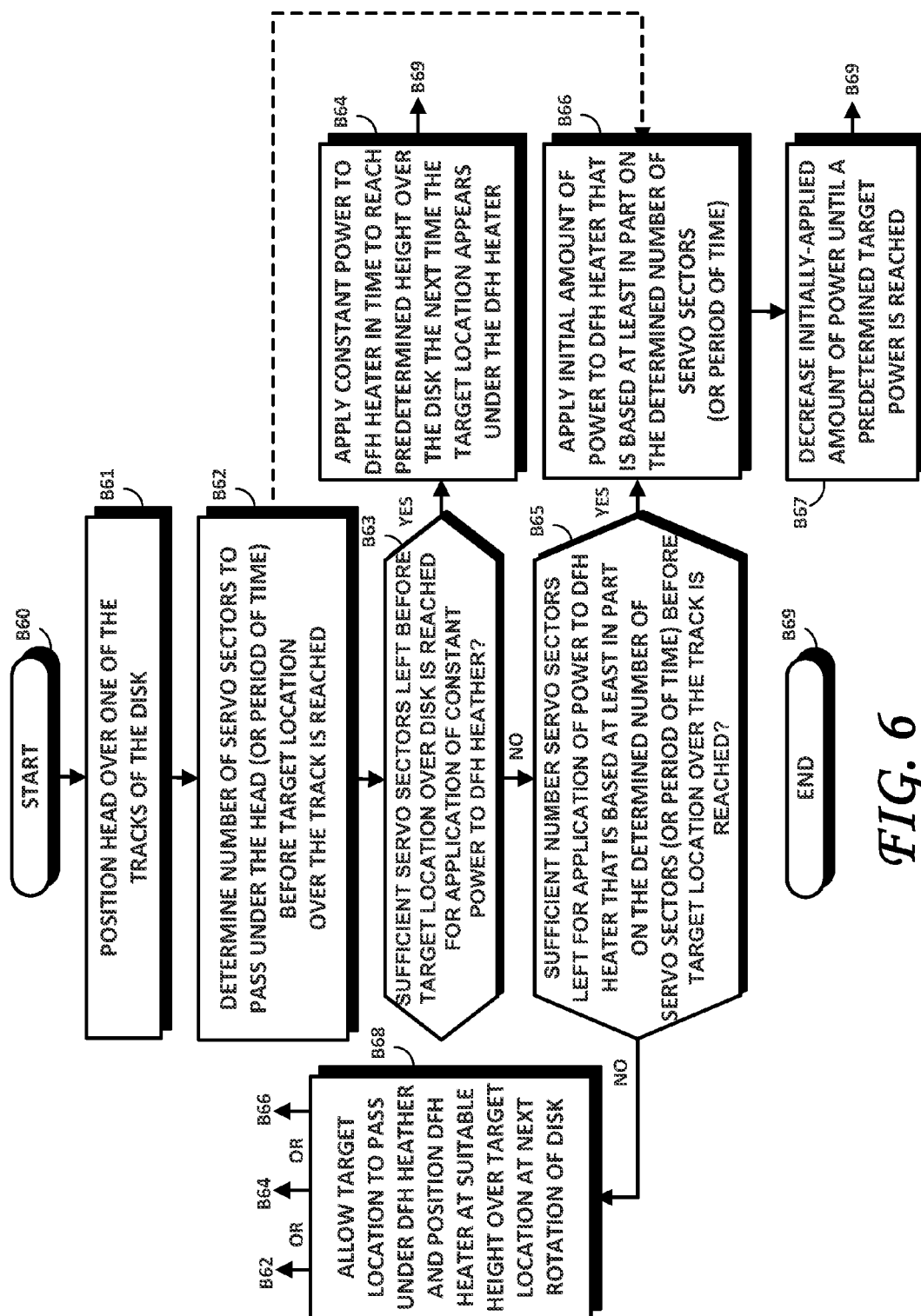
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FIG. 1
(Prior Art)



**FIG. 4****FIG. 5**



PER WEDGE PREHEAT DFH TO IMPROVE DATA STORAGE DEVICE PERFORMANCE

BACKGROUND

Disk drives comprise a disk and a head connected to a distal end of an actuator arm that is rotated about a pivot by a voice coil motor (VCM) to position the head radially over the disk. The disk comprises a plurality of radially spaced, concentric tracks for recording user data sectors and servo sectors. The servo sectors comprise head positioning information (e.g., a track address) which is read by the head and processed by a servo control system to control the velocity of the actuator arm as it seeks from track to track.

Because the disk is rotated at a constant angular velocity, the data rate is typically increased toward the outer diameter tracks (where the surface of the disk is spinning faster) in order to achieve a more constant linear bit density across the radius of the disk. To simplify design considerations, the data tracks are typically banded together into a number of physical zones, wherein the data rate is constant across a zone, and increased from the inner diameter zones to the outer diameter zones. This is illustrated in FIG. 1, which shows a disk format 2 comprising a number of data tracks 4. The disk format of FIG. 1 also comprises a number of servo sectors 6₀-6_N recorded around the circumference of each data track. Each servo sector 6_i comprises a preamble 8 for storing a periodic pattern, which allows proper gain adjustment and timing synchronization of the read signal, and a sync mark 10 for storing a special pattern used to symbol synchronize to a servo data field 12. The servo data field 12 stores coarse head positioning information, such as a track address, used to position the head over a target data track during a seek operation. Each servo sector 6_i further comprises groups of servo bursts 14 (e.g., A, B, C and D bursts), which comprise a number of consecutive transitions recorded at precise intervals and offsets with respect to a data track centerline. The groups of servo bursts 14 provide fine head position information used for centerline tracking while accessing a data track during write and read operations.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a representation of a conventional disk format.

FIG. 2 is a diagram illustrating aspects of one embodiment.

FIG. 3 shows a head according to one embodiment, comprising a dynamic fly height (DFH) actuator and a temperature sensitive fly height sensor (TSS).

FIG. 4 is a chart illustrating exemplary fly height profile over time, illustrating aspects of one embodiment.

FIG. 5 is a chart illustrating exemplary DFH power profile over time, illustrating further aspects of one embodiment.

FIG. 6 is a flowchart of a method according to one embodiment.

DETAILED DESCRIPTION

FIG. 2 shows a disk drive configured to apply an initial amount of power to a DFH heater and decrease the amount of power applied to the DFH heater until a predetermined height of the head over the track is reached, according to one embodiment. As shown, the disk drive may comprise a disk 16 comprising a plurality of tracks 17, a head 18, a voice coil motor (VCM) 20 and a microactuator 22 for actuating the head 18 over the disk 16. The disk drive further comprises a controller 24 configured to execute a method according to one embodiment as shown, for example, in FIG. 5, among its

other disk-controlling duties. As shown, the disk 16 comprises a plurality of servo sectors 30₀-30_N that define the plurality of tracks 17. The controller 24 processes read signal 34 to demodulate the servo sectors 30₀-30_N into a position error signal (PES). The PES is filtered with a suitable compensation filter to generate a control signal 36 that is applied to VCM 20, which rotates an actuator arm 38 about a pivot in order to position the head 18 radially over the disk 16 in a direction that reduces the PES. The servo sectors 30₀-30_N may comprise any suitable position information, such as a track address for coarse positioning and servo bursts for fine positioning.

According to one embodiment, any suitable microactuator 22 may be employed, such as a piezoelectric (PZT) actuator that transduces electrical energy into a mechanical displacement. In the embodiment of FIG. 2, the microactuator 22 is integrated with and actuates a suspension 39 that couples the head 18 to the actuator arm 38. However, the microactuator 22 may be integrated at any suitable location, such as with a slider to which the head 18 is mounted. In addition, the microactuator 22 may comprise multiple actuators (e.g., multiple PZTs) that may cooperate to move the head 18 in different radial directions. The controller 24 may be configured to perform the methods and functionality described herein, with particular reference to FIGS. 4-5.

In operation, an air bearing forms between the head and the disk due to the disk rotating at high speeds. Since the quality of the write/read signal depends at least in part on the fly height of the head, conventional heads (e.g., a magnetoresistive heads) may comprise a heater that controls the fly height through thermal expansion.

FIG. 3 shows a head 300 according to one embodiment. The head 300 comprises a DFH heater 306 that is operable to actuate the head 300 vertically over the disk 16. The head 300 may further comprise a temperature sensitive fly height sensor (TSS) 304 operable to generate a fly height signal (FHS) representing a fly height of the head 300 over the disk 16. The disk drive may further comprise control circuitry operable to execute the flow diagram of FIG. 5, to control the fly height of the head 300 as described herein and as shown, for example in FIG. 4. A conversion function may be configured to convert the FHS expressed in first units (e.g., volts) into a corresponding fly height (FH) of the head 300 expressed in second units (e.g., nm). The DFH 306 may comprise any suitable actuator, such as a heater that actuates through thermal expansion, or a piezoelectric actuator that actuates through mechanical deflection. As also shown in FIG. 3, the head 300 comprises a suitable write element 28, such as an inductive coil, and a suitable read element 302, such as a magnetoresistive element. In one embodiment, the aforementioned control circuitry calibrates a DC control signal applied to the DFH 306 in order to maintain the head 300 at a desired fly height during write/read operations (where a different target fly height may be used for write and read operations). The topography of the disk 16 may vary for any number of reasons, including a warpage of the disk 16 caused by an uneven clamping force when clamping the disk 16 to a spindle motor that rotates the disk 16. In one embodiment, the DC control signal applied to the DFH 306 may be modulated by an AC control signal so that the head 300 follows the topography of the disk 16 during write/read operations and to selectively implement the fly height profiles described herein, representative exemplars of which are shown in FIGS. 4 and 5.

Upon receipt of a write command, the disk drive may apply a constant amount of power to the DFH heater to lower the head 300 to a predetermined write height over the disk 16, as the disk 16 rotates under the head 300. As the constant amount

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of power is applied to the DFH heater **306**, the head takes a predetermined amount of time to transition from an initial track following fly height to a fly height that is suitable for the write element **308** to write to the disk **16**. This fly height may be determined, for example, during pre-manufacturing activities. This predetermined amount of time may be calculated for the track and target location on the disk **16** on which the write operation is to be carried out. However, if the drive determined that target location will appear below the head **300** before the head **300** is flying at the correct fly height for the write element **308** to write to the target location, the disk drive must resort to waiting for another revolution of the disk **16** for the target location to come under the head **300**. This calculation may be made, for example, by measuring the wedge-to-wedge time between successive wedges as the disk **16** rotates under the head **300**. It may be appreciated that since the head **300** takes a finite period of time to transition from an initial fly height to a fly height suitable for write operations, there is conventionally a minimum period of time from application of the constant power to the DFH heater **306** to the time at which the TSS **304** generates a signal that is representative of the head **300** flying at the correct height to carry out the write operation. Such minimum period of time may, for example, be measured in servo sector wedges. Conventionally, if the drives determines that target location would appear under the head **300** sooner than that minimum period of time or minimum number of servo sector wedges, the disk drive will have to allow the disk **16** to complete another revolution to enable the head **300** to be lowered to its predetermined fly height in a timely manner though the application of a constant amount of power. For example, conventionally, it may take a period of time roughly equivalent to the time necessary for 40 wedges to pass under the head **300** as the disk **16** rotates thereunder.

According to one embodiment, however, that minimum period of time or number of wedges may be shortened or decreased, respectively. According to one embodiment, if this minimum period of time is shortened or number of wedges decreased, the disk drive may exhibit less latency, as the head **300** may be positioned at a fly height suitable for writing sooner than it would otherwise be.

FIG. 4 is a chart illustrating a fly height profile over time, illustrating aspects of one embodiment. FIG. 5 is a chart illustrating a DFH power profile over time, illustrating further aspects of one embodiment. The chart of FIG. 4 plots the fly height of the head over the rotating disk as a function of time (measured in servo wedges here), for both the constant power level conventionally applied to the DFH heater **306** and an amount of power to the DFH heater **306** that is dependent at least in part on the determined number of servo sectors or determined period of time. The power profile according to one embodiment is not constant, as shown by the “per wedge preheat DFH power” curve of FIG. 5. This initial application of power (e.g., 120 mW as shown in FIG. 5) may be higher than it would otherwise be had the applied power been maintained at the conventional constant level (e.g., 60 mW as shown in FIG. 5). According to one embodiment, this initial, higher application of power to the DFH heater may be decreased until a target power is reached. According to one embodiment, at or around that target power, the head (and/or the write element **308**) reaches a height over the track of the rotating disk at which the head **300** is operative to perform data access operations, including write operations.

This height over the track may be reached, according to one embodiment, earlier (or in fewer servo wedges) than it otherwise would had a constant power level have been applied to the DFH heater. As shown in exemplary FIG. 4, from an

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initial, track following height of 3.5 nm, a predetermined height of 1.5 nm at which data access operations may be carried out is achieved after about 40 wedges have passed under the head when the conventional constant power level is applied to the DFH heater and is achieved, in the exemplary embodiment of FIG. 4, after only about 23 wedges have passed under the head. This time savings of time in reaching the height of 1.5 nm at which data access operations may be carried out may result in better drive performance characteristics, such as lower average seek times.

According to one embodiment, the head **300** may be positioned over one of the tracks of the disk **16**. Such track may be the track containing the target location at which a command is to be initiated. The controller **24** may then determine the number of servo sectors 30_N to pass under the head **300** before the target location over the track is reached by the head **300**. Alternatively, the controller **24** may be configured to determine the period of time before the head **300** passes over the target location over the track. Thereafter, according to one embodiment, the controller **24** may apply an initial amount of power to the DFH heater **306** that is dependent at least in part on the determined number of servo sectors or determined period of time. In this manner, a lower wedge count (or shorter period of time) until the target location may be correlated, according to one embodiment, with a higher initially-applied power to the DFH heater **306**. Conversely, a higher wedge count (or longer period of time) until the target location may be correlated, according to one embodiment, with a comparatively lower initially-applied power to the DFH heater **306**. This initially-applied power may be changed (e.g., decreased) after each or a selected number of servo sectors pass under the head **300**. Alternatively, a determination or calculation may be made after each or a selected number of servo sectors pass under the head **300**, to determine whether to maintain the current level of applied power or whether the applied power should be changed (e.g., decreased). The decrease itself, according to one embodiment, need not be constant. Indeed, the rate at which the applied power is decreased may itself change over time.

Thereafter, the controller **24** may cause the amount of power applied to the DFH heater **306** to be decreased until a target power to the DFH heater **306** is reached, which target power may be correlated with a predetermined height over the track or with a height at which certain data access operations (such as write operations) may be carried out. According to one embodiment, this height may be the height at which the head **300** may carry out write operations using the write element **308**. Also according to one embodiment, the initial power applied to the DFH heater **306** may be higher than it would otherwise be had the applied power been constant. The control of the decrease of the initially-applied amount of power to the DFH heater, according to one embodiment, may be carried out in an open loop fashion. According to one embodiment, however, the control of the decrease of the initially-applied amount of power to the DFH heater may be carried out in a closed-loop fashion. That is, according to one embodiment, the decrease of the initially-applied amount of power to the DFH heater may be continued until a monitored, calculated or otherwise derived height of the head **300** over the track is reached.

According to one embodiment, the initially-applied amount of power may be selected to be, for example, between about 10% and about 100% greater than the constant amount of power conventionally applied to the DFH heater. FIG. 5 shows an example in which the initially-applied power according to one embodiment may be higher (e.g., 120 mW) than the conventionally-applied constant power level (e.g., 60

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mW). As shown in FIG. 5, this initial higher power level applied to the DFH heater may then be decreased until a predetermined or target power is reached, which target power may be associated with a height of the head over the track that is suitable for read and/or write operations. In this manner, the head 300 may be disposed at or near the desired height when the head 300 passes over the target location 410 (at which write operations are to be initiated, for example). As shown in FIG. 5, the initially-applied power (or applied at any point in the DFH heater power profile of FIG. 5) may be decreased in a monotonic manner. The decrease may be carried out using any suitable profile. For example, the applied power may be continuously (or continuously decreased in a stepwise manner at the minimum control resolution) decreased or the applied power may be decreased in a piece-wise linear manner. The timings of the successive decreases in applied power may be varied at will, as they need not be regular. The DFH heater power profile or profiles may be predetermined and stored in a non-volatile memory and/or may be calculated on the fly. The stepped decreases in power applied to the DFH heater may be timed according to detected wedge boundaries, for example. According to one embodiment, the combination of higher initially applied power and decreases in applied power may be configured such that the head does not overshoot the targeted fly height. This ensures both correct write operations and prevents the head 300 from contacting the surface of the disk 16 or dipping below an optimal height over the rotating disk.

FIG. 6 is a flowchart of a method according to one embodiment. As shown therein, the method starts at B60 and block B61 calls for positioning the head 300 over one of the tracks of the disk. Thereafter, the number of servo sectors to pass under the head (or period of time) before the target location over the track is reached may be determined, as shown at B62. According to one embodiment, block B66 may then be carried out, as indicated by the dashed arrow line between B62 and B66. B66 calls for applying an amount of power to the DFH heater that is based at least in part on the number of servo sectors (or period of time) that was determined in block B62. As noted above, that initial application of power may be higher than it would otherwise be had the applied power been maintained at a constant level. Lastly, block B67 calls for the power applied to the head 300 to be decreased until a target power level is applied to the DFH heater. At or around that time, in some situations, the head 300 should be flying at a height above the track containing the target location that is suitable for read and/or write operations. In some situations, such as when greater power is applied or power is applied earlier, the head 300 may reach the target height well before the target location.

According to one embodiment, after block B62, block B63 may be carried out. In block B63, the disk drive may determine whether a sufficient number of servo sectors or wedges are yet to pass under the head 300 that would allow sufficient time for the application of constant power to the DFH heater in time for the head 300 to reach the predetermined height over the target location by the next time the target location passes under the disk (i.e., without waiting for an additional rotation of the disk). If YES, the method may proceed to previously described block B64. If, however, there are an insufficient number of servo sectors or wedges yet to pass under the head 300 such that there is insufficient time for the application of constant power to the DFH heater (NO branch of B63), the method may proceed to B65.

In B65, it may be determined whether there are a sufficient number of servo sectors or wedges for carrying out B66 and B67 in time for the target power to be reached by the next time

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the target location passes under the heads 300. If YES, then the method may proceed to previously-described Blocks B66 and B67. If there are an insufficient number of servo sectors or wedges that are yet to pass before the target power to the DFH heater is reached (NO branch of B65), the method may proceed to B68. In B68, the target location may be allowed to pass under the head 300 without attempting to lower the head to a height suitable for read/write operations and the method may proceed to B62. B68, effectively, allows the disk to rotate another rotation, at which point there should be sufficient time before the target location again appears to apply the constant power to the DFH heater, as shown at B64. Alternatively, blocks B66 and B67 may be carried out after the target location passes under the head 300 and the disk rotates another rotation. The method ends after either block B69 or B67. Alternatively, the method may revert back to B61, where the head may be positioned over the same or over another track for access to another target location on the disk. In this manner, the controller 24 may be configured to selectively apply the constant power W_K or a relatively higher power level (e.g., between about 10% and about 100% of the constant power W_K), followed by successive decreases thereof until the target height over the disk is achieved. Alternately still, the controller 24 may be configured to only apply the higher power level and decrease the applied power until the target power to the DFH heater is reached, irrespective of period of time available or the number of wedges to pass under the head until the target location is reached.

While certain embodiments of the disclosure have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the disclosure. Indeed, the novel methods, devices and systems described herein may be embodied in a variety of other forms. Furthermore, various omissions, substitutions and changes in the form of the methods and systems described herein may be made without departing from the spirit of the disclosure. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the disclosure. For example, those skilled in the art will appreciate that in various embodiments, the actual physical and logical structures may differ from those shown in the figures. Depending on the embodiment, certain steps described in the example above may be removed, others may be added. Also, the features and attributes of the specific embodiments disclosed above may be combined in different ways to form additional embodiments, all of which fall within the scope of the present disclosure. Although the present disclosure provides certain preferred embodiments and applications, other embodiments that are apparent to those of ordinary skill in the art, including embodiments which do not provide all of the features and advantages set forth herein, are also within the scope of this disclosure.

The invention claimed is:

1. A data storage device comprising:

a disk comprising a plurality of tracks, each track comprising a plurality of data sectors and a plurality of servo sectors;

a spindle motor for rotating the disk;

a head actuated radially over the disk, the head comprising a dynamic fly height (DFH heater); and

control circuitry configured to:

position the head over one of the tracks;

determine a number of servo sectors to pass under the head before a target location over the track is reached;

apply an initial amount of power to the DFH heater that is dependent at least in part on the determined number of servo sectors; and

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decrease the initially-applied amount of power before the target location comes under the head until a predetermined target power is reached.

2. The data storage device of claim 1, wherein the initially-applied amount of power is greater than a constant amount of power necessary for the head to reach the target location at a predetermined height without decreasing the applied power.

3. The data storage device of claim 2, wherein the initially-applied amount of power is between about 10% and about 100% greater than the constant amount of power.

4. The data storage device of claim 1, wherein the control circuitry is further configured to decrease the power applied to the DFH heater after each of the determined number of servo sectors passes under the head.

5. The data storage device of claim 1, wherein the power applied to the DFH heater is maintained substantially constant during at least a portion of a time between next adjacent servo sectors pass under the head.

6. A method of operating a data storage device, the disk drive comprising a disk comprising a plurality of tracks, each track comprising a plurality of data sectors and a plurality of servo sectors, a spindle motor for rotating the disk, and a head actuated radially over the disk, the head comprising a dynamic fly height (DFH) heater, the method comprising:

positioning the head over one of the tracks;

determining a number of servo sectors to pass under the head before a target location over the track is reached; applying an initial amount of power to the DFH heater that is based at least in part on the determined number of servo sectors; and

decreasing the initially-applied amount of power applied to the DFH heater before the target location comes under the head until a predetermined target power is reached.

7. The method of claim 6, wherein the initially-applied amount of power is greater than a constant amount of power necessary for the head to reach the target location at a predetermined height without decreasing the applied power.

8. The method of claim 7, wherein the initially-applied amount of power is between about 10% and about 100% greater than the constant amount of power.

9. The method of claim 6, wherein decreasing decreases the power applied to the DFH heater monotonically.

10. The method of claim 6, further comprising maintaining the power applied to the DFH heater substantially constant during, at least a portion of a time between next adjacent servo sectors pass under the head.

11. A data storage device comprising:

a disk comprising a plurality of tracks, each track comprising a plurality of data sectors and a plurality of servo sectors;

a spindle motor for rotating the disk;

a head actuated radially over the disk the head comprising a dynamic fly height (DFH) heater; and

control circuitry configured to:

position the head over a given one of the tracks; determine a period of time before the head reaches a target location over the given track;

apply an initial amount of power, while the head is over the given track, to the DFH heater that is dependent at least in part on the determined period of time, the initially-applied amount of power being an amount of power of a plurality of amounts of power that are each dependent upon an amount of time before the head reaches a target location on a track being followed; and

decrease, while the head is over the given track, the initially-applied amount of power applied to the DFH

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heater during the period of time until a predetermined target power is reached, the predetermined target power being associated with a height, of the head over the given track, that is suitable for read and/or write operations.

12. The disk drive of claim 11, wherein the control circuitry is further configured to determine the period of time by at least measuring a wedge-to-wedge time between two of the servo sectors.

13. A method, comprising:

providing a disk drive, the disk drive comprising a disk comprising a plurality of tracks, each track comprising a plurality of data sectors and a plurality of servo sectors, a spindle motor for rotating the disk, and a head actuated radially over the disk, the head comprising a dynamic fly height (DFH) heater;

positioning the head over a then one of the tracks;

determining a period of time before the head reaches a target location on the given track;

applying, while the head is over the given track an initial amount of to the DFH heater that is dependent at least in part on the determined period of time, the initially-applied amount of power being an amount of power of a plurality of amounts of power that are each dependent upon an amount of time before the head reaches a target location on a track being followed; and

decreasing, while the head is over the given track, the initially-applied amount of power applied to the DFH heater during the period of time until a predetermined target power reached, the predetermined target power being associated with a height of the head over the given track that is suitable for read and/or write operations.

14. The method of claim 13, wherein determining the period of time comprises at least measuring a wedge-to-wedge time between two of the servo sectors.

15. A data storage device comprising:

a disk comprising a plurality of tracks, each track comprising a plurality of data sectors and a plurality of servo sectors;

a spindle motor for rotating the disk;

a head actuated radially over the disk, the head comprising a dynamic fly height (DFH) heater; and

control circuitry configured to:

position the head over one of the tracks;

determine a number of servo sectors to pass under the head before a target location over the track is reached; apply an initial amount of power to the DFH heater that is dependent at least in part on the determined number of servo sectors; and

before the target location comes under the head, decrease the initially-applied amount of power after each or the determined number of servo sectors, until a predetermined target power is reached.

16. A method of operating a data storage device, the data storage device comprising a disk comprising a plurality of tracks, each track comprising a plurality of data sectors and a plurality of servo sectors, a spindle motor for rotating the disk, and a head actuated radially over the disk, the head comprising a dynamic fly height (DFH) heater, the method comprising:

positioning the head over one of the tracks;

determining a number of servo sectors to pass under the head before a target location over the track is reached;

applying an initial amount of power to the DFH heater that is based at least in part on the determined number of servo sectors; and

before the target location comes under the head and until a predetermined target power is reached, decreasing the initially-applied amount of power applied to the DFH heater after each or the determined number of servo sectors passes under the head.

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